Management Guidelines for the Welfare of Zoo Animals

The Giant Pacific Octopus
Enteroctopus dofleini

Management Guidelines for the Welfare of Zoo Animals – The Giant Pacific Octopus *Enteroctopus dofleini*
Matt Slater and Oliver Buttling 2011

Published by the British and Irish Association for Zoos and Aquariums,
Regent's Park, London NW1 4RY, United Kingdom

ISSN 0963 – 1712

Enteroctopus dofleini in Public aquaria

Giant Pacific Octopus Husbandry Manual

BIAZA Aquarium Working Group - Cephalopod Focus Group

Matt Slater and Oliver Buttling 2011

Contents

Species characteristics

Kingdom Animalia

Phylum Mollusca

Class Cephalopoda

Order Octopoda

Family Octopodidae

Genus *Enteroctopus*

Species *Dofleini*

Enteroctopus dofleini, the Giant Pacific octopus (GPO) is a member of the cephalopod molluscs, an ancient group of highly evolved, active and intelligent predators. Cephalopods (literally meaning 'head-foot') possess the distinguishing characteristics of a complex nervous system, eggs that generally hatch into miniatures of the adult form (no larval stage) and eight tentacles or arms surrounding the mouth. This group includes the octopus, squid, cuttlefish and nautilus.

The GPO is the largest of all the octopus species, normally between 3 and 4 metres and ranging from 20 to 40 kilos (Hartwick, 1983). The largest recorded GPO was 71 kg (Cosgrove and Mc Daniel 2009). Anecdotal reports of giant pacific octopus with an armspan of 9 metres have been given.

Octopus have no bones and are soft bodied, the bag shaped mantle on the dorsal part of the octopus contains the internal organs and is commonly reddish brown in colour, usually darker in males than in females. This red colour helps GPO's avoid detection in the murky low light levels they inhabit.

These amazing creatures depend on stealth and camouflage to avoid predation and are able to change their colour, pattern and texture to perfectly blend in with their environment and to display to other octopuses. Chromatophores are highly developed pigment filled cells with radial muscles which enable the cell to rapidly expand and contract. This allows dramatic instantaneous changes of colour and pattern. Colour changes can range from pale grey to dark brown, to dark red and to complement and enhance these, the GPO is also able to change the texture of its skin from smooth to bumped and spiny, even horned, through the activity of circular muscles. Many people believe that octopus emotions are betrayed by the colour they display however this is difficult to prove. The arrays of GPO colour and texture in relation to camouflage are currently being investigated at Brighton Sealife Centre, UK.

The GPO has highly developed senses that enable many of the extraordinary abilities characteristic to these creatures. Each of the 8 arms (in four pairs) possess up to 280 individual suction cups distributed in two rows, these contain thousands of chemical receptors used for taste and smell along with areas around the outer edge of the suckers that are sensitive to touch. The suction cups are also able to rotate and move independently of the other suckers. These abilities allow the octopus to distinguish between objects through touch alone, a skill particularly utilised when groping for prey in small dark spaces. In addition to this they also have the most developed eye and visual ability of all the invertebrates. The octopuses are generally considered to be the most intelligent invertebrate animals and have the most complex brain, with the capacity for both long and short term memory. As such these creatures are able to solve and remember puzzles and problems through trial and error and experience.

The octopus generally moves about by crawling, using its arms, but it can move more rapidly by torpedoing along, jetting water through the siphon. When doing this to escape a threat a cloud of purple black ink may also be released to confuse a potential predator. This ink can be concentrated or watery dependent on the amount produced and can be projected out of water at unsuspecting aquarists! In aquaria inking is very unusual and fortunately ink in the water is not toxic to the animal.

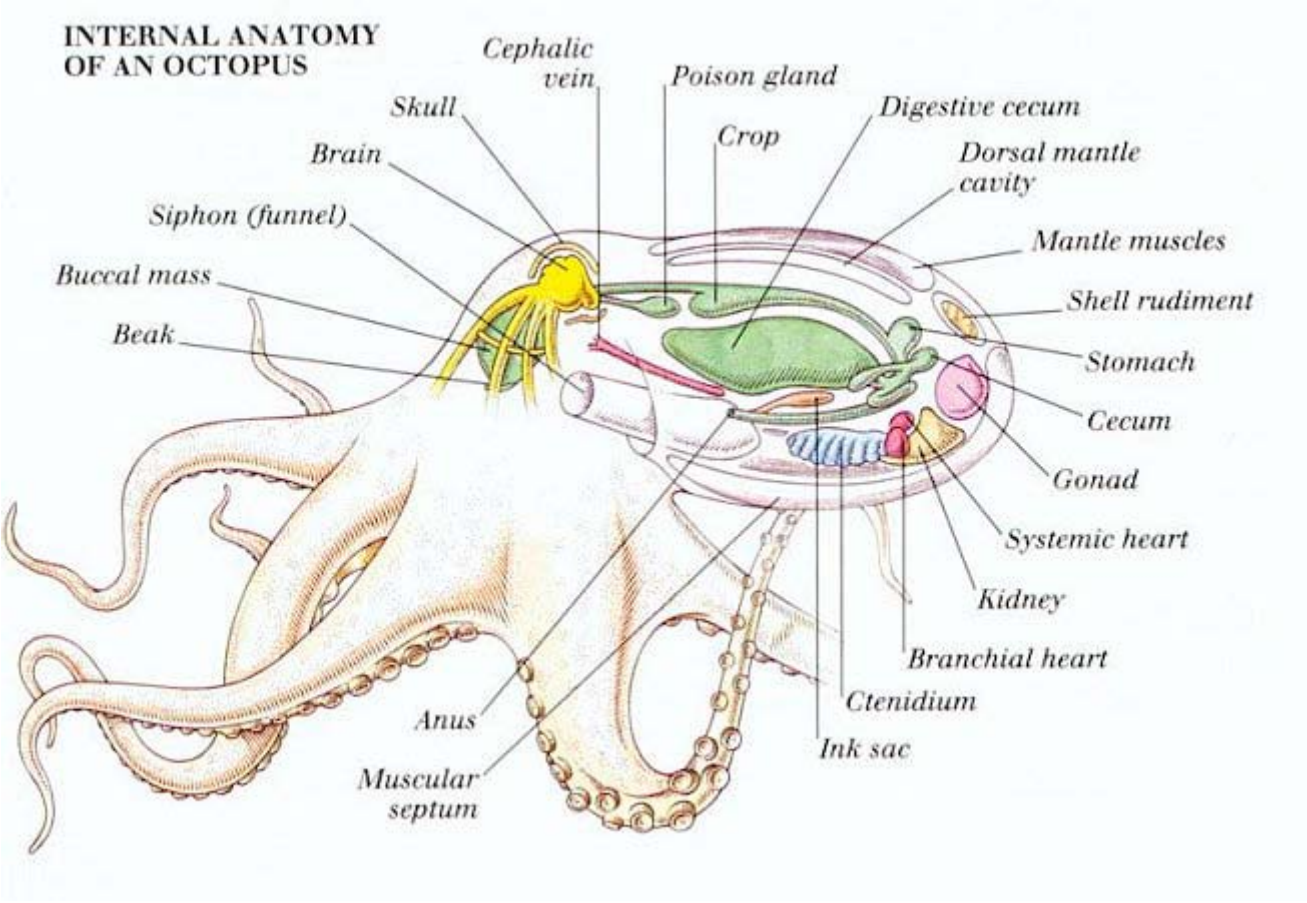

Figure 1 Octopus anatomy

(http://universe-review.ca/R10-33-anatomy.htm)

Octopuses are capable and determined escape artists that are able to squeeze through any gap that is larger than the beak (the only hard part of the animal).

Octopus can be found foraging at night in the shallower intertidal zone and have even been known to climb right out of the water and pull themselves across rocks to reach tidal pools. Out of the water the mantle cavity holds water enabling the gills to continue extracting oxygen until the water is depleted of oxygen. After this the animal is effectively holding its breath. This terrestrial behaviour is seldom observed in daylight although a captured octopus in a bucket aboard a boat will often be found by the fishermen crawling up sheer surfaces making it's way back to the ocean!

The GPO is an opportunistic and formidable predator. It is crepuscular (most active at dawn and dusk) and feeds on a wide variety of creatures, predominantly crustaceans (crab and lobster in particular), but also bivalve molluscs (such as mussels and clams), snails, fish, catsharks and other octopus.

Using the web-like net between their 8 arms octopus are able to parachute down onto a crab, and tucking in the edges it cuts off all escape routes. Its hundreds of suction cups on the legs are used to feel and taste for the crab and then when discovered to pin it down and bring it to the beak.

A variety of techniques are employed by the octopus to enable access to the flesh inside their mostly hard shelled prey (Anderson & Mather, 2007). Brute force is often used to rip or bite open the shell. The keratin beak can bite a hole through the joints of a crustaceans shell and when opening bivalves a rasp like radula can also be used to drill a hole through the shell. Saliva containing a potent neurotoxin called cephalotoxin and digestive enzymes is then injected to swiftly kill the prey within a few seconds of being bitten. The enzymes are so effective that all the connective tissue and thinner parts of the shell are dissolved in approximately 20 minutes for an average sized shore crab (Slater pers observation). After the digested crab is sucked out only the carapace and stronger sections of the claws and legs remain to be discarded.

The diversity of prey species can be observed at the entrance to the octopuses lair, where the discarded remains of the shells and bones of previously consumed prey are deposited, known as the midden.

Geographic Range

GPO's are found in the cold coastal waters of the temperate northern Pacific from southern California through Alaska and down the Western Pacific coast as far as Korea. They are most common in shallower waters (2m – 30m) but are found at depths as great as 300m.

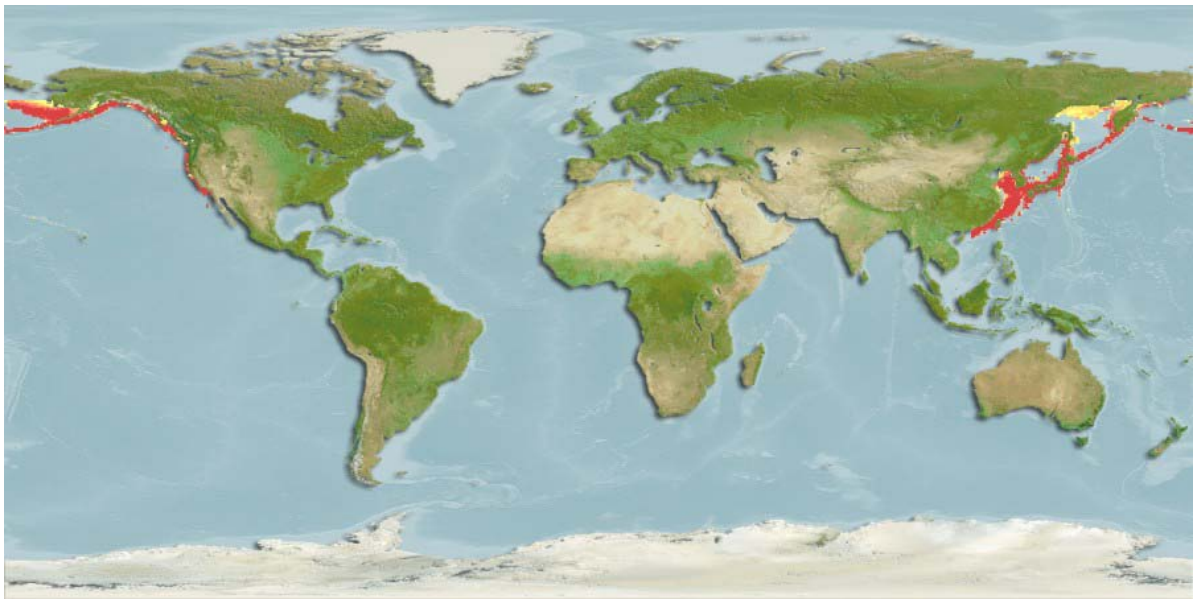

Figure 2. Geographic Range of the GPO (red areas)

This species inhabits the benthic zone of rocky reefs and kelp forests. Among the boulders and crevices in these habitats the home range of the octopus includes a den, made using existing spaces or through excavation of the substrate. These areas are used for feeding and resting, in addition to serving as a refuge from predators (such as halibut, harbour seals, orca, sperm whales and sea otters) and as brooding chambers.

Conservation status

There is little information on the GPO population conservation status, though it is not currently considered threatened.

This species is fished commercially; cephalopods have long been a valuable human food source with an estimated 3 million tonnes of cephalopods caught globally each year. For centuries Giant Pacific octopuses have been targeted by fishermen for food and as bait for halibut fishing off the west coast of Canada and America. Around Vancouver the annual landings of octopus have fluctuated widely – they averaged less than 22 tonnes until 1987, then increased to 200 tonnes in the late 1980s when

demand for halibut bait increased. The fishery reached a peak in 1997 at 217 tonnes -118 tonnes from the dive fishery and 99 tonnes from the trap and trawl fishery, but landings decreased to 26 tonnes in 2005. Demand for octopus as bait declined when halibut quota was assigned on an individual basis made the fishery less competitive (Cosgrove and McDaniel, 2009)

There is anecdotal evidence that the number of extremely large GPOs being spotted and caught in Canadian waters has decreased (Anderson 1995) in the last 50 years but this is difficult to back up with concrete evidence. The sheer size of the coastline and the low density of the human population along it make the current level of fishing sustainable. Catching Giant Pacific octopus is not easy, modern fisheries today include trap and dive fisheries as well as a limited by-catch trawl fishery. Catching giant octopus in mobile fishing gear such as bottom trawls is fairly unusual as they tend to stay around rocky sea beds, which snag on mobile gear. They also are not likely to be caught in monofilament fishing lines as they don't tangle easily and find it relatively easy to escape. Crab pots can be dangerous to GPOs but in most cases they are able to escape before the pots are hauled.

Studies of fishing impact on octopus species suggest that the reproductive strategy of octopuses make them far less vulnerable to overfishing. The short period of time before juvenile octopus reach maturity and produce a large number of offspring allows populations to recover far more rapidly than many other marine species. Over fishing of other species has resulted in reduced predation on GPO's, reduced competition for invertebrate prey and may explain stable catch per unit effort data collected on octopus stocks around Hokkaido island Northern Japan (Rigby et al 2005).

Populations in shallow waters are likely to be vulnerable to habitat threats resulting from human activities, being particularly sensitive to pollution. No protection is provided under CITES or IUCN Red list legislation and there are no current targeted conservation actions, though populations of this species are known from several North American Marine National Parks.

Display justification

Octopus have long been hugely popular with visitors to public aquaria. Victorian naturalist and gentleman Henry Lee of Brighton aquarium famously stated that “An aquarium without an octopus is like a plum-pudding without plums“(Lee 1875).

At Blue Reef Aquarium Newquay, the giant Pacific octopus ranked as second most popular animal at the aquarium after sharks, beating seahorses, rays, turtles, clownfish and corals (visitor surveys between 2001 and 2011). Interactive feeding demonstrations with the giant octopus are the most popular talks of the day and of all the educational talks these receive the most positive comments in surveys. People are fascinated by these alien creatures and as a result of this attention grabbing creature aquarium staff are able to educate far more customers that otherwise would leave without a conservation message. It is well known that the majority of aquarium visitors do not read signs but all are happy to listen to an engaging, interesting and short commentary from an enthusiastic biologist. As long as ethical considerations are fully addressed the keeping of this species has considerable benefits.

Figure 3. 'Duffy' the octopus in quarantine at Blue Reef Aquarium Newquay

Collection

Giant Pacific octopuses can be acquired from licensed collectors in the USA, Canada and Japan. Divers capture octopus to order, usually small specimens are preferred as they acclimate better to captive conditions and have a longer life expectancy in captivity. Fish anaesthetics, MS222 or Quinaldine in alcohol, are used to flush the octopus out of its lair and once in open water it is wrestled into a plastic fish bag. In the past collectors used chlorine solutions and even copper sulphate but although working well they obviously harmed the specimens and surrounding invertebrates considerably. Hydrogen peroxide is now used by a lot of collectors (Anderson 1995), this would annoy the octopus but as hydrogen peroxide rapidly breaks down to water and oxygen it is less damaging. It is extremely rare for a GPO to react aggressively when being collected – in 30 years of collecting in Canadian waters Phillip Bruecker says he has never been attacked but a collegue Doug Pemberton is featured with one trying to grab him repeatedly on a You Tube video.

Routine Movements

Octopuses should be handled carefully to ensure no damage is caused to their delicate skin. To move octopus from one tank to another the best way is to spend some time getting the octopus used to human interaction. Once they associate humans with food and play they enjoy interacting and will usually come straight over to the edge of the tank – it is then relatively easy to net them in a soft net or scoop them into a fish bag or bucket. I have moved young active GPO's in this way many times and have even been able to lift them out of the water into a large bucket as they grip onto you very firmly if they are in the mood (and hungry).

Moving a grumpy senescent octopus can be more difficult as they tend to hold fast onto the rocks / hide in their lair. In this case it is often easiest to drain the tank and once they are exposed to air they are more likely to let go of the rocks and as they slip down towards the water you can manhandle them (firmly but gently) into a suitable bongo or large bucket.

Health and Safety

When working with giant Pacific octopus it is important to be careful not to allow the octopus to bring your hand or arm close to the beak – a bite from a giant Pacific octopus is very painful and can be very serious. The Neurotoxin the GPO uses to kill crabs is in the saliva and a bite although rare could be dangerous to humans. Enzymes in the saliva are used to digest the flesh of crustacean prey and this can cause a necrotic wound that does not heal and swells badly. To date no fatalities have been recorded from GPO bites, but bites must be avoided, and a bite requires

urgent medical attention. The application of heat is recommended to counter the effects of the neurotoxin and enzymes (Anderson 1999).

Aquarists need to be fully trained before working with this species. To begin with it is good practice to only allow arm tips to stick onto you and to ensure one hand is always free so that you can safely remove the octopus if you want to. At Blue Reef we have a rule that you should only have a maximum of 3 arms holding onto you at any one time- As you become more relaxed and you get to know your octopus you can let them get more arms on you. Even small giant octopuses are capable of pulling you very hard when they want to. Suction cups are capable of producing 'love bites' on the skin although they soon fade (unfortunately) and humans don't have any adverse reactions to contact.

If you want a giant Pacific octopus to let go of you simply squeeze its arm firmly – they don't like it and will always let go quickly. Be careful not to dig into the flesh with your nails. It seems to be very difficult to injure the arm of an octopus but obviously don't squeeze it so hard that the arm is damaged, stay calm and gradually apply pressure until the animal stops holding on. They soon learn that you are not food and you rarely need to squeeze them hard more than a few times before they know not to mess with you!

It has been observed at Blue Reef Newquay that a giant Pacific octopus will recoil if touched by warm dry hands – and will often let go of the keeper – this is risky if a member of the public touches the octopus while a keeper is holding the animal out of the water as it may fall out of the tank so our policy is not to let people touch the octopus without wet hands.

It is also important to wash hands carefully before interacting with octopus to remove soaps / hand creams etc that may harm the octopus. They do love the taste of fish on your skin though!

Despite all these factors overall the risks involved with octopus enrichment are relatively easy to control and the benefits of regular enrichment and play out-weigh these risks.

Transportation

Giant Pacific octopuses are regularly shipped to Europe from Canada via air in insulated 'octo-barrels'. These are plastic food/liquid barrels with a sturdy lid held shut by a metal clamp, padded out with a generous layer of loft insulation. The octopuses are starved for 10-14 days prior to shipment to ensure the water is not soiled too much. Water is pre cooled before shipping to 3 degrees C less than ambient temperature to ensure that the temperature stays cool for the transport. Heavy duty large fish bags are used to hold the specimen and the volume of water

should be at least twice the volume of the octopus (Anderson 1995). The specimen should be triple bagged as it is not impossible for them to bite a hole in a bag; the bags filled with pure oxygen and knotted or tied using elastic bands or cable ties. The barrels should be insulated with rock wool loft insulation or similar and cold packs used to keep the temperature low during transit.

Acclimation

When acclimatising giant Pacific octopuses there is little evidence that acclimation needs to be overly protracted. Spending 30 minutes or so mixing the tank water with the bag water using a jug is fine in my experience. Often after a 25 hour journey it is more important to get them out of the high levels of ammonia they are swimming in than it is to worry about slight stresses caused by changes in salinity, pH or temperature. In 10 years of doing this I have never had any problems and all the octopus feed well straight away on arrival. Some other curators disagree and recommend a slower acclimation – Chris Brown at Weymouth Sealife DDD recommends 1.5 - 2 hours to avoid stress of changing pH.

Water parameters

Salinity –They live in pure seawater 33 – 36 ppt.

Temperature – The temperature of the species range from 6 ºC - 11 ºC. There is evidence that temperatures between 12 and 13 ºC are harmful over long periods. (Anderson pers comm.). Roland Anderson is pushing for aquariums to keep them cooler, as low as is practical for the chilling unit. Evidence from the Alaska Sealife Center in Sward, Alaska shows that octopuses can live up to five years at 5-8 deg C. giving aquariums longer to exhibit, train and show individual animals, and cutting down the expense of acquiring a new animal every year. Of course this will lead to more expense of running the chiller unit and will lead to more condensation on the glass of a tank, but it should be offset by less expense of animal acquisition.

They are not at all tolerant to sudden changes in temperature and well maintained highly reliable chilling equipment is essential for keeping this species. It is also important that chillers and heat exchangers are made from non corrosive materials as metals (especially copper) are extremely dangerous to octopus. Titanium is a suitable alternative.

Temperatures of 12 degrees lead to increased activity and can lead to animals jetting and damaging the mantle – this doesn't always but can result in infection and possible death so is to be avoided.

Ammonia levels should be zero and Nitrite levels should be ≤ 0.3 mg/l

Nitrate levels – GPO's are able to withstand elevated concentrations of Nitrate as high as 50ppt but again should not be stay at these levels for a long time. A base level should range from 0 to 25 mg/l.

Phosphate also does not seem to be critical to octopus.

pH Octopuses prefer slightly alkaline pH levels; 7.5 – 8. Rapid pH changes can stress octopuses.

Dissolved Oxygen Water should be well aerated but not supersaturated; 85-104.

Artificial sea water

Natural sea water seems to provide best results when keeping octopus.

According to Kerry Perkins of Brighton Sealife Centre certain brands of artificial sea water have caused problems with Cephalopods in the past, lack of certain micronutrients in the artificial make up can cause deformed growth in statolith's although more studies need to be done.

Metals

Octopuses are sensitive to metal concentrations particularly copper and tin (as are all molluscs).

Tank design

Lids

The fact that octopuses are able to leave water and walk on land was known in Aristotles time but it was not until the advent of public aquaria that we knew that octopus will willingly escape in order to forage for prey Henry Lee, 'Natl'ralist' of Brighton Aquarium writes

> *"In May, 1873, it was found that some young lump-fish {Cyclopterus luvipiis^ were mysteriously disappearing from one of the tanks..... One morning, however, Mr. Lawler, one of the staff, on going to count our young friends, found an interloper amongst them.*
>
> *"Who put this octopus in No. 27 tank?" he inquired of the keepers. " Octopus, sir ? no one ! Well, if he ain't bin and got over out of the next tank ! " And this was just the fact. The marauding rascal had occasionally issued from the water in his tank, and clambered up*

the rocks, and over the wall into the next one ; there he had helped himself to a young lump-fish, and, having devoured it, returned demurely to his own quarters by the same route, with well-filled stomach and contented mind."

Many similar reports of octopuses escaping have been documented over the years since as a result it is common knowledge that an octopus aquarium needs a tightly fitting lid! Lids have successfully been constructed out of wood, fibreglass, plastic coated wire and net (always stretched taught across the top of the tank). GRP grating has been show to contain copper (Horniman Museum 2010) and may not be suitable for use in tanks although the Deep used this material as a lid for many years. Gaps in lids for pipes etc can be filled with filter floss which seems to repel octopus.

Biological filtration

Regarding maintenance of water quality Anderson states that the preferred method is flow through of natural sea water. This is not always possible and when keeping this species in European aquariums it is rarely possible due to sea water temperatures being outside of the preferred range for much of the year. Additionally waste water from GPO tanks flowing back into the sea could potentially carry diseases and larvae to the local environment. For this reason it has until recently been a condition set by CEFAS (Centre for Environment, Fisheries and Aquaculture Science) that any discharged water is treated with caustic soda to kill potential pathogens. The repeal of this regulation in 2010 has been welcomed by public aquaria as using caustic soda is impractical and as yet there is no evidence that diseases are a problem and no UK aquaria to date are attempting to breed this species in captivity.

Filtration of octopus tanks can be achieved using many different methods- reverse flow under gravel filtration with a top over flow is the method used at Blue Reef Newquay, and at Blue Reef Portsmouth (See diagram), this allows the removal of shed skin from suction cups that otherwise build up on the substrate. Obviously screens on the overflow are essential to prevent octopuses escaping and also to prevent them blocking the overflow– plastic coated chicken mesh is sufficient to prevent octopus escaping through the overflow but to be on the safe side a double overflow to prevent it being blocked by an octopus has been plumbed in. Double overflows have also been used at Weymouth DDD octopus quarantine system to prevent an animal blocking the overflow and flooding the place.

Recommended flow rates through a biological filter for a GPO tank do not need to be furiously fast – the Newquay display with a total volume of 6284l has an AG 8 Pump (10228 litres per hour) giving a turnover time of 1.6 turnovers per hour.

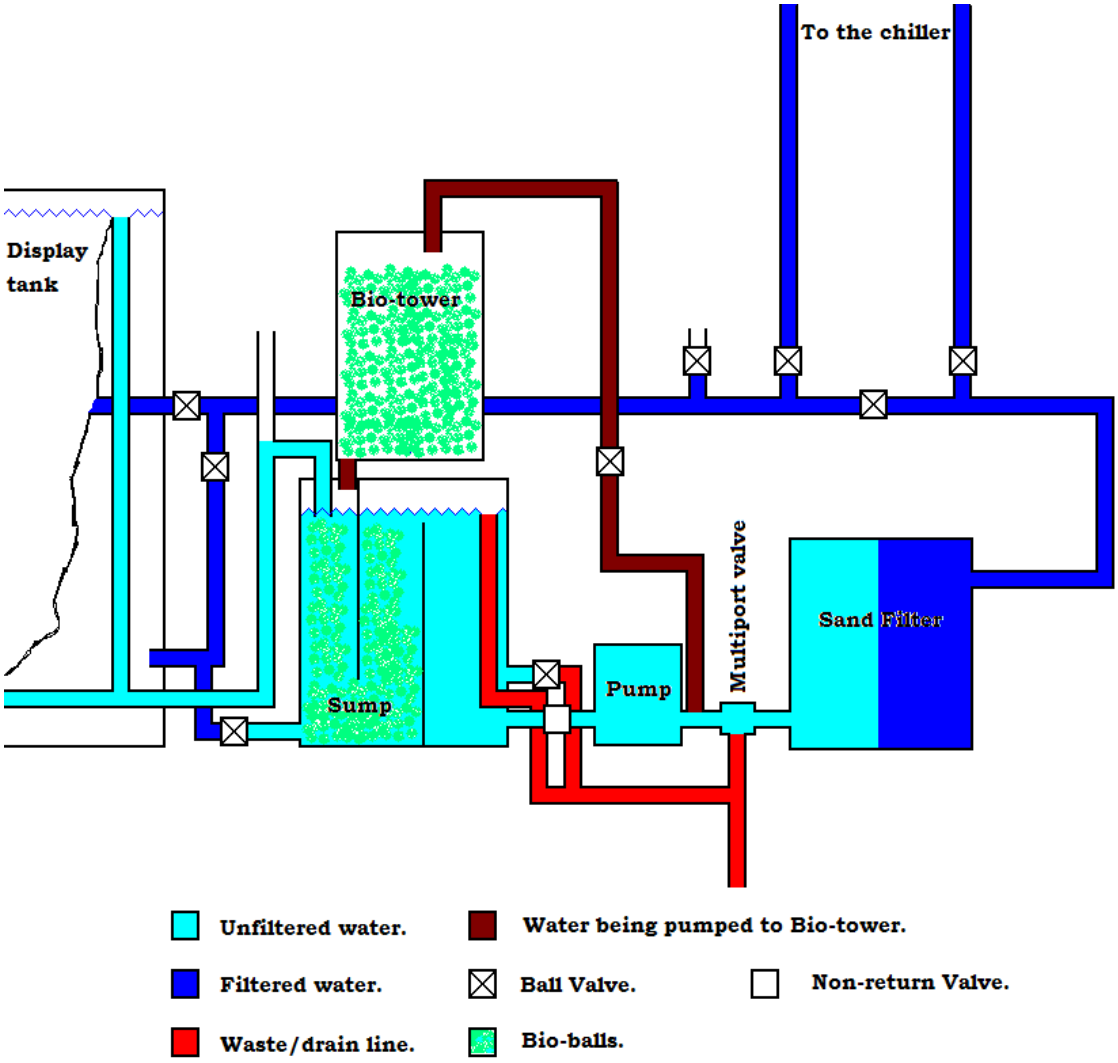

Figure 4. Schematic diagram of filtration at Blue Reef Portsmouth GPO display (James Wright)

Aeration / Gas supersaturation

Oxygen levels in a giant pacific octopus display need to be high. Fortunately cool water naturally holds more oxygen which is one reason why giant Pacific octopuses are so much larger than their tropical cousins. Using air diffusers in GPO tanks are not a good way to achieve this as the air bubbles can get caught in the web and mantle – stretching the skin and sometimes ripping the webbing. Movement of water through the filtration system should agitate or replace (through overflow) the surface constantly to ensure oxygenation.

Gas saturation is dangerous to giant Pacific octopus – any breaks in the pipework on the suction side of the pump can potentially cause supersaturation.

Water sterilization

The use of Ozone in protein skimming has been shown to have a detrimental effect on the health of cephalopods and for this reason it is **not** recommended to be used for GPO tanks. UV is a suitable alternative for water strerilization but it is not always necessary if frequent water changes are being carried out.

Electrical safety

Regarding electrical safety it is important to remember these octopuses are able to direct jets of water out of the tank if they feel like it. For this reason electrical sockets and appliances in the area of the tank should be IP rated (preferably water proof) to prevent electric shocks.

Theming / Decor

In his comprehensive paper entitled ‘Aquarium husbandry of the giant Pacific octopus’ (1995). Roland Anderson describes the incredible ability of octopus to find their way behind theming rockwork- certainly fibreglass back drops are more of a problem for this than more modern concrete backdrops which are heavier and tighter fitting. Certainly well constructed rockwork shouldn’t cause a problem in this way.

It is important in my opinion for all species to create as natural a habitat as possible within the aquarium- rock work should be built with an indent suitable for the octopus to use as a lair – this doesn’t necessarily need to be deep enough for the octopus to disappear from view completely but it should be deep enough for the octopus to feel secure. Flat sided rockwork resembling brick or stone work that is popular with many aquarium designers massively detract from the effect of an octopus display – making it appear that the animal is in a prison cell.

Artificial kelp is good for decorating the display (Pangea produce hard wearing fake kelps) and it is useful to use vertical theming such as floating ropes and buoys to break up open water spaces – this reduces the chances of the octopus picking up speed and jetting into the sides of the tank.

Tank size

The size of giant Pacific octopus display is an important consideration – given a suitable quantity of food giant octopuses will rapidly grow to at least 2 meters arm span within 6 months of arrival as a 50cm juvenile. On a normal diet (see below) they should not get much larger than this but it is important that they have space to move around freely and exhibit normal feeding and foraging behaviour. A cylindrical

tank of 2m diameter and 2m depth at Blue Reef Aquarium Newquay seems to provide adequate space (6284 litres).The triangular shaped GPO tank at Seattle aquarium designed by Dr Roland Anderson has a total volume of 13,638l. It is arguable that you could give a GPO too large a display as particularly in males their activity increases prior to senescence as they have a hormonal urge to find females. Given a very large tank they can potentially injure themselves by crashing into rockwork when jetting backwards. Also a larger display can mean that the octopus is further away from customers and is not as visible – potentially negating the purpose of the display.

Figure 5. The GPO tank at the Seattle Aquarium is a 10 feed wide cylinder and is 5 foot deep

Quarantine tank facilities

Qurantine tanks for giant Pacific octopus don't need to be quite as large as a display tank as they usually will not hold a full size active adult octopus. Instead they are more likely to be used to house newly arrived young specimens or senescent adults. At blue reef Newquay a 2m diameter circular vat is used with sand filtration and a lid made of netting. Weymouth Sealife Displays Development Department have recently installed a large system with 2 square tanks with removable dividers enabling up to 4 octopus to be kept in each tank at one time. Tanks are 2.4m x 2.4m x 1.2m depth (actual water depth 0.8-1M). This provides 4 tanks of 1.2m cubes.

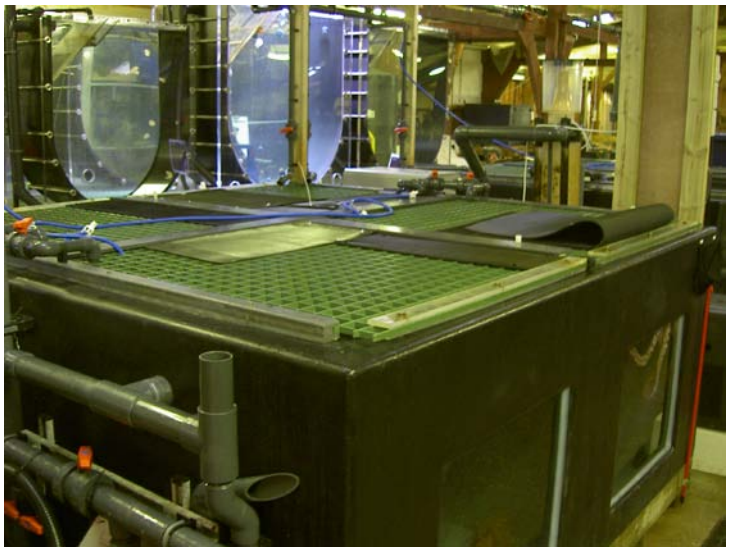

Figure 6. Multiple GPO holding facility at Weymouth Sealife DDD

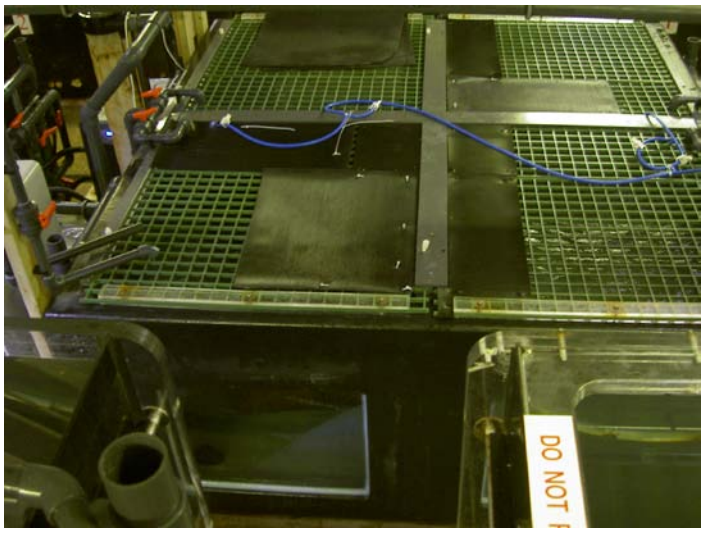

Figure 7. GPO holding facility at Weymouth Sealife DDD

Another consideration is that water should not be mixed between tanks holding senescent octopus and younger octopus as it has been shown that hormones carried from the senescent octopus can affect the behaviour of a younger animal (Slater pers. Obs.)

Display tank design considerations

Tanks with curved acrylic fronts have the advantage of deflecting a jetting octopus rather that stopping it dead and causing damage to its mantle tip.

Having easy access to the top of the tank is important to allow easy maintenance – also worth considering is having access from the front of the tank so that aquarists can engage with the public when playing with the octopus – this makes for a much more exiting and engaging talks when carrying out octopus enrichment plays and feeds.

It is important to consider the effects of condensation caused by tank water being considerably colder than the surrounding air. Condensation is reduced by using thick acrylic for viewing windows as opposed to less insulating standard glass. Additionally air flow should be set up blowing dry air onto windows. If you are not able to do this soap can be used to lather the glass – when the tiny bubbles clear this reduces condensation build up for a short period.

Lighting

Subdued lighting using LED or fluorescent tubes is sufficient – Use of red light gives an un-natural appearance and has no known benefit as octopus are able to adapt to low levels of white lighting. It has been observed in several aquariums that when regularly given enrichment during the daytime they will switch to being very active during daylight hours. An incident at the Sea Star aquarium, Coburg, Germany where a GPO managed to extinguish a 2000w metal halide lamp by squirting a jet of water at it out of the top of the tank suggests that this level of lighting is too bright!

Flash Photography

Repeated flash from visitors seems to have a negative affect on an octopus making it less likely to be active during the day, and sometimes causing visible flinching. No actual health problems have been linked to flash photography, however most aquariums now ban flash photography and this is particularly important with this species. Limited amounts don't seem to put off a friendly octopus during play time though. Negative affects are far more likely to be seen when an animal is nearing senescence or guarding eggs.

Dietary requirements

Giant Pacific octopus are specialist feeders that feed in the wild on the Red Rock crab *Cancer productus* and the extremely fast Dungeness crab *Cancer magister*. In European aquariums the closest to this is to use the brown crab *Cancer pagurus*. Feeding them on large crabs like this is expensive and as an alternative that they seem to really enjoy shore crabs *Carcinus maenas* and velvet swimming crabs *Necora puber* can be used. At Blue Reef Aquarium Newquay the GPO is fed on one large live shore crab per day and although the octopus could eat more it has been found that this amount keeps them active and hungry at every feed. On this diet they have been shown to live a long healthy life but to not out grow the display tank. At Seattle aquarium Dr Roland Anderson prefers to feed his GPOs on a diet of shell free raw sea food; *"such as herring, smelt, squid, fish fillets, or clam meat (geoduck fillets or surf clams) in order to minimize the need to clean the bottom of the tank of crab remnants, which are visually unattractive and may contain bits of uneaten food, which may foul the tank. Food without shells is usually eaten completely, and if not, can be netted out of the tank. Amounts fed at the Seattle Aquarium are about 1-2 % of the octopus' body weight per day."*

If you have sea stars in the tank they do a good job of cleaning up any left-overs from crab shells. Crabs are a more natural diet and are far less oily than most fin fish so for this reason live crabs are used at Blue Reef Newquay. Using a long handled net with a mesh size larger than the diameter of the pieces of substrate the shells can easily be removed without removing the substrate. Oily fish such as mackerel or sand eel are used only in tiny quantities as treats when baiting enrichment devices such as jars and toys.

Tank mates

GPO's are loners and more than one should not be kept in an aquarium together. According to an Octopus collector Philip Bruecker in the wild despite the fact that they are not sociable they can be found as close at 2-3 meters from each other in suitable habitat and a 100 m band of suitable habitat can have 10 adults or more. In the aquarium brittle stars and other sea stars are compatible. Fish have been used by some aquariums but the predatory nature of GPOs makes fish selection critical – only pelagic and active fish should be chosen and they must be species that won't hurt the octopus. Famously in one American aquarium a GPO was filmed eating its tank mate, a one metre long smooth hound shark!

Health

Due to their short lifespan and rapid growth phase followed by a sudden onset of senescence after breeding, giant pacific octopus like all cephalopods rarely seem to suffer from disease. Common ailments in captivity are scratches causing white patches on the mantle and tentacle edges – these will heal in young individuals but in adults they will rarely heal as an adult octopus is soon to invest all its energy and its life in reproduction. The same is true of their powers of regeneration, a juvenile octopus can re-grow a lost limb but an adult will not bother to do the same.

One specimen transported from Canada to Blue Reef Aquarium Newquay that died 3 weeks after arrival was found on post mortem to have a mild colonisation of gill epithelia by coccidial parasites, presumed to be a species of *Aggregata*, perhaps *Aggregata dobelli* (Pathologist Dr Mark Stidworthy). Whether this was the definite cause of the animals death could not be conclusively proven.

Stress caused by changes in temperature or chemical pollution with copper or other metals can produce disease like symptoms in GPOs.

Signs of stress or poor health or senecence in octopus are;

- Repeated pacing around the tank (Stereotypical behaviours),
- Sitting under water returns for prolonged periods of time,

- Looking pale and motionless for more than 3 days (this sometimes happens if they have been over fed –they won't move for up to 3 days but no longer.)
- Intense curling of the arms (not to be confused with curling when shedding suction cups)
- Autophagy (eating their own arms)
- Large white patches forming on skin.

Quarantine protocol

If moving an octopus into a closed system exhibit there is little need to quarantine the animal. No prophylactic treatments are recommended currently when quarantining this species. If a system contains more than one octopus this should be reconsidered as it is feasible that a disease could be introduced.

Reproduction and life history

GPO's live from 3 to 4 years, potentially to 5 years in colder Alaskan waters and they are able to grow to 180kg. However most adult animals mature at 20 – 30kg (Hartwick 1983) meaning that a 10 kg octopus has about one years viable exhibit time (Anderson 1995).

Reproduction for this species is most common in the winter, mating is the only time this solitary species usually get together, albeit briefly. GPO's as with most other octopuses are semelparous, breeding only once in their lifetime.

During mating the male octopus uses the hectocotylised (modified) tip of the third right arm called the *ligula* to deposit a spermatophore packet (in strands up to 1 metre long) through the mantle cavity to the oviduct of the female.

Figure 8. Ligula of Mr Tickle, a male GPO – note the arm in the background has a 10 cm long section at its tip

After an interval of up to 42 days the female GPO then lays 20,000 to 100,000 small eggs, (each egg is approximately the size of a grain of rice) depending on body size (Anderson, 1995) in clusters of 200 to 300 eggs over a period of days, attached to the overhanging rock of her den. The eggs are tended for the duration of their incubation by the female through aeration, washing and grooming, ensuring that they are healthy and safe from parasites and predators. The incubation period is dependent on water temperature, but can last from eight to twelve months, shortly after which the female dies as she will not leave the eggs during this time to feed. During the brooding period the female utilises protein metabolism to stay alive, reducing in size by up to half her weight when the eggs were laid. (Anderson, 1995) Males generally die within three months of mating, though they are able to mate with

other females before doing so.

Figure 9. Female GPO guarding eggs

The newly hatched young are around the size of a grain of rice with proportionally shorter arms and bigger eyes than the adult form. The hatchling octopus drift among the plankton for four to twelve weeks, free swimming by continual jet propulsion and feeding independently from the water column before beginning their settlement phase as small juveniles on the seafloor, about which little is yet known. The GPO lives for 3 to 5 years, reaching sexual maturity after approximately one year. Captive GPO's in public aquariums are thought to achieve similar life spans to their wild counterparts.

Senescence (a form of old age) is a physiological process that occurs at the end of the lifespan of a mature octopus and can last several months. Secretions from the optic gland control a process of ripening of the reproductive organs, inactivation of salivary and digestive glands and cessation of appetite (Anderson, 1995). The activation of these optic gland secretions appears to be affected by environmental factors such as light, temperature and nutrition (Anderson, 1995). The consequence of senescence and the processes controlling is the starvation and death of the octopus after breeding.

Some of the characteristic indicators of the onset of octopus senescence are loss of appetite and weight, 'hollow eyes' caused by retraction of the surrounding skin, an increased level uncoordinated and undirected activity and the presence of white lesions on the skin that do not heal (Anderson, 2002). The healing processes of octopuses are shut off from the onset of senescence (Van Heukelem 1977), resulting in the presence of lesions that would normally heal in a younger, healthy animal.

As octopuses have no fat reserves senescent octopus metabolise muscle to generate energy and eventually at the end of their senescence they can be half their original body weight.

Management of senescence in public aquaria

A senescent giant Pacific octopus is inactive and depressed looking. For this reason **it is better if an animal nearing this stage of their lifecycle is moved to a suitable off show, shady enclosure** to live out their retirement. This is better for the animal and better for customers – nothing upsets people more than seeing a pale senescent octopus slowly wasting away.

There is an ethical dilemma here as some people feel that the slow wasting away of a senescent animal may cause the animal suffering and humane euthanasia is offered by some as an alternative.

Interaction with octopus after they have laid eggs / reached senescent is not to be encouraged. Most GPOs will push you away when they are in this state, and won't hold on to you or any other objects. As their natural behaviour is to focus on guarding their eggs this interaction may well stress the animal. Occasionally there have been reports of sociable senescent animals; after egg laying one giant Pacific octopus at Blue Reef Hastings continued to be interactive although she repeatedly attempted to bite, which is unusual for this species. As a rule interaction is not recommended once a GPO reaches old age.

Euthanasia of Giant Pacific Octopus

These large animals are not easily euthanized due to their toughness and size. Magnesium chloride is an effective sedative and a large dose will eventually kill a GPO. Sue Thornton recommends using pentabarbitone injection as a speedier alternative.

Environmental and behavioural enrichment

Live food is important not only for dietary reasons but also as a form of enrichment. Brittlestars and other echinoderms may also provide enrichment. Making sure that the display is as naturalistic as possible with plenty of rocks and fake seaweeds for the octopus to move around helps to keep them occupied.

A flow of water into the tank also seems to be appreciated by some individuals.

Regular interaction with keepers seems to be actively enjoyed by all giant Pacific octopus except for those who have reached senescence.

Figure 10. Octopus enrichment 'Playtime' at Blue Reef Aquarium Newquay

Incorporating regular octopus enrichment feeds into the daily talks schedule ensures that the octopus is being regularly interacted with. At these events the octopus has the opportunity to display a behaviour that is only usually associated with vertebrate animals. Some individual giant Pacific octopuses really seem to enjoy rough play and will cling onto a keepers arm allowing it to be pulled right out of the water. At BRA Newquay a GPO named Mr Tickle loved being tickled with a frayed polypropylene rope so much so that he would let go completely of the edges of the tank and could be spun around and around in the centre of the tank.

It is not uncommon for a friendly octopus to enjoy wrestling so much that it refuses to eat, even if it is hungry until it is sure the aquarist has packed up and closed the lid!

As well as hands on interaction, toys and other enrichment devices can also be used to keep the octopuses' environment changing and to keep them working for their food. Many different enrichment devices have been used over the years at public aquariums. Famously octopus can unscrew lids of jars although it appears that not all individual GPO's are capable of working this out. Plastic toys that can contain

food such as Mr Potato head are a great way of getting an octopus to work for its food.

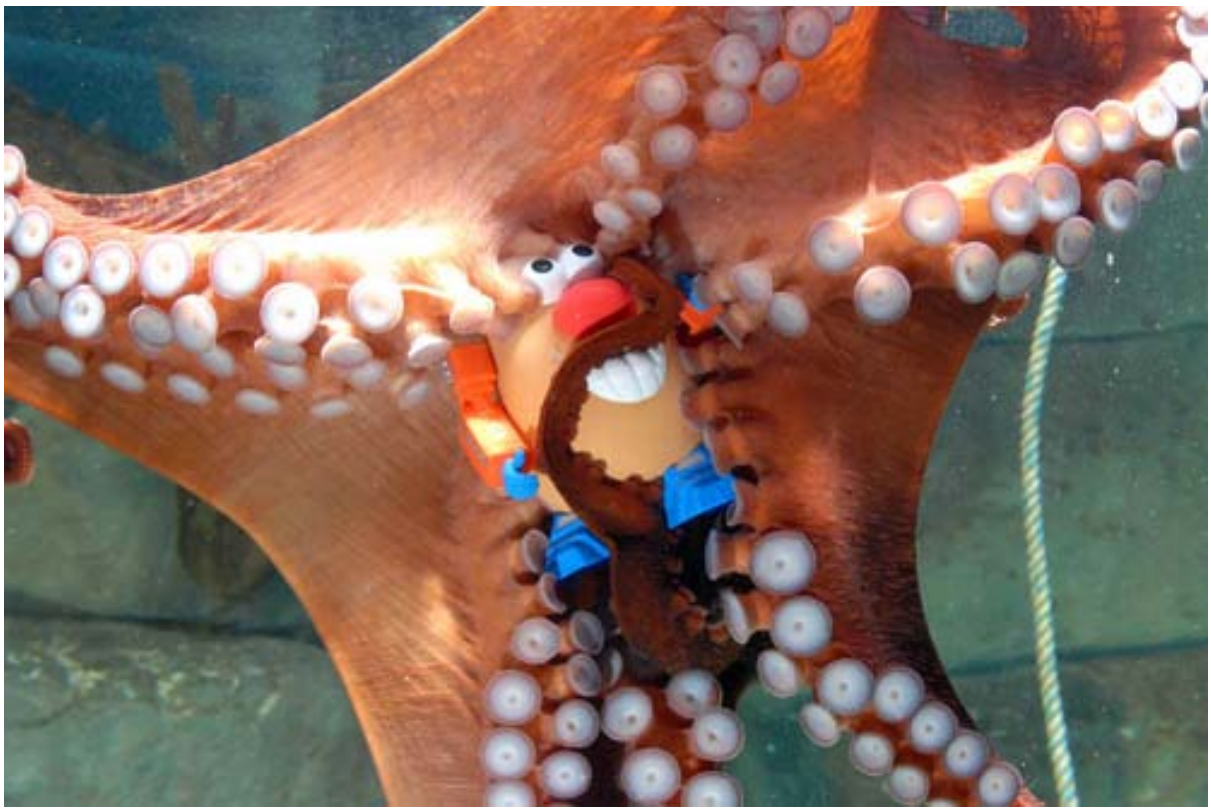

Figure 11. Mr Potato Head being enjoyed by 'Sassy' at Blue Reef Aquarium

At Blue Reef Newquay a student from Cornwall college, Paul Martin created a clear Perspex box called the ‘octobox’ (equipped with clear suckers for attaching to the acrylic of the tank) that could be baited with food. The octopus had to open the door to get to the food. The system was modular enabling a latch device to be fitted – once the octopus had mastered pulling open the door – it then had to learn to lift the latch –the final stage – twisting a handle was never mastered by a GPO!

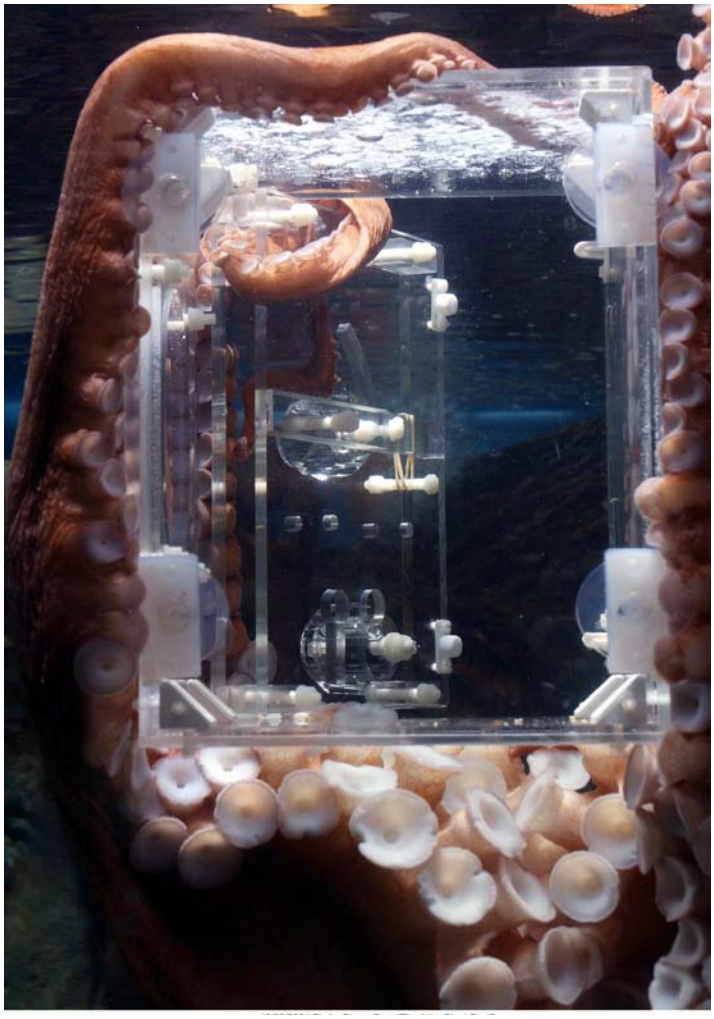

Figure 12. Titan opens the Octobox

Live crabs should not be used to bait jars or box traps such as these, as they must suffer intense stress whilst watching an octopus attempt to open the device! – instead it is preferable to use small pieces of mackerel or other oily fish.

Other successful enrichment devices used by aquariums around the world include- toy boats, Lego boxes, Rubix cubes, child proof pill containers, baby toys, and even the prediction of world cup football matches!

Frozen octopus lollies have been made by the staff at Blue Reef Newquay by freezing in a coke cup sea water containing shore crabs / mysis shrimp/ Krill/ sand eels and other sea food. These icy treats are really relished by GPOs who don't seem put off at all by the cold!

For a thorough list of enrichment devices that can be used please refer to the octopus enrichment handbook compiled by Mark Rehling of Cleveland Metropark Zoo (Rehling 2001).

Figure 13 Matt giving Mr Tickle an octo lolly

Acknowledgements

Matt and Olly would like to particularly thank the following people for their help with putting together this Husbandry Manual;

Dr Roland Anderson, Seattle aquarium

Kerry Perkins, Brighton Sealife Centre

Chris Brown, Sealife Displays Development Department, Weymouth

Paul Hale, London Sealife Centre,

James Wright, National Marine Aquarium, Plymouth

Robbie Robinson, Blue Reef Aquarium, Portsmouth

Philip Bruecker, Living Elements, Vancouver

References;

Anderson, R, C. (2009) Husbandry Advances in Aquarium Husbandry of the Giant Pacific Octopus (*Enteroctopus dofleini*) AZA

Anderson, R. C. (1995) *Aquarium husbandry of the giant Pacific octopus*. *Drum and Croaker* 26:14-23

Anderson, R, C (1999) *An Octopus Bite and its Treatment*, The Festivus, 1999, 31(4):45-49

Anderson, R.C. & J.A. Mather (2007) *The packaging problem: bivalve prey selection and prey entry techniques of the octopus Enteroctopus dofleini*. Journal of Comparative Psychology. 121:300-305

Anderson, R.C., J.B. Wood, and R.A. Byrne (2002) *Octopus senescence: the beginning of the end*. Journal of Applied Animal Welfare Science. 5(4):275-283

Cosgrove J. A. And McDaniel N. (2009) *"Super Suckers"* Harbour publishing British Columbia

Hartis, C. (2011) *"Enteroctopus dofleini*", (On line) Animal Diversity Web.

Hartwick, E.B. (1983) *Octopus dofleini*. 277-291 in P.R. Boyle (ed). Cephalopod life cycles, Volume I - Species Accounts. Academic Press, London. Vol. 1

Rigby, P. Robin; Sakurai, Yasunori. (2005) *"Multidimensional Tracking of Giant Pacific Octopuses in Northern Japan Reveals Unexpected Foraging Behaviour ".* Marine technology Society Journal, Vol. 39.

Lee, H. (1875) *"The octopus or devilfish of fiction and of fact".* Brighton aquarium notes. 15:1-114.

http://www.archive.org/stream/octopusordevilfi00leeh/octopusordevilfi00leeh_djvu.txt

Wildscreen (2010) *"North Pacific Giant Octopus (Enteroctopus dofleini)"* (On Line) ARKive: Images of life on Earth

MarineBio Conservation Society "*Enteroctopus dofleini, Giant Octopus"* (On line) marinebio.org

Van Heukelem, F.W. (1977) *Laboratory maintenance, breeding, rearing, and biomedical research potential of the Yucatan octopus* (*Octopus maya*). Laboratory Animal Science. 27:852-859

Rehling, M, J. (2001) *Octopus enrichment techniques*. Drum and Croaker Volume 32: 8-15